Magnetic Resonance Angiography in Vertebrobasilar Ischemia

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Background and Purpose: Magnetic resonance angiography is a new, noninvasive technique whose diagnostic value in vertebrobasilar artery disease has not yet been determined.

Methods: Forty-one patients with acute cerebellar and/or brain-stem ischemia were examined by routine magnetic resonance imaging, extracranial and transcranial Doppler ultrasound, and selective intra-arterial arteriography. Results were correlated with magnetic resonance angiography. Magnetic resonance angiography was accomplished using a three-dimensional time-of-flight gradient-echo technique.

Results: Magnetic resonance angiography correctly identified all occlusions, stenoses, and aneurysm within the distal vertebrobasilar system as revealed by conventional intra-arterial arteriography but missed the diagnosis of vertebral artery dissection in one case. This results in a sensitivity of magnetic resonance angiography of 97% and a specificity of 98.9%. However, the degree of stenoses was difficult to evaluate by magnetic resonance angiography. At least for severe obstructive lesions, this drawback can be eliminated by application of presaturation pulses, which allow the analysis of flow direction and collateral blood flow. Doppler ultrasound studies add useful hemodynamic information for less severe degrees of stenoses.

Conclusions: The combined use of magnetic resonance angiography and Doppler ultrasound findings may replace the invasive intra-arterial arteriography examination in many patients with suspected macroangiopathy of the vertebrobasilar arteries. (Stroke. 1993;24:1310-1315.)

KEY WORDS • angiography • magnetic resonance imaging • ultrasonics • vertebrobasilar circulation

Ischemia of the vertebrobasilar territory often arises from cardiac embolism or atherosclerotic disease, leading to hemodynamic vascular failure or serving as a source of artery-to-artery embolism.1 Less usual reasons are vertebral artery dissection,2 fibromuscular dysplasia, or arterial dolichoectasia.3 The prognosis of vertebrobasilar artery occlusive disease depends on the severity of obstruction and the efficacy of adequate collateral circulation development,4 while importance of the site of lesion is controversial. Proximal vertebral artery stenoses have formerly been considered to represent a low incidence of infarction; however, in a recent study its large potential for embolicigenic infarction has been emphasized.5 Distal vertebral and basilar artery stenoses seem to carry a higher risk for brain-stem infarction.6,7

New treatment regimens such as intravenous or intra-arterial lysis are progressively established and promising for future use, especially if noninvasive verification of the causative vascular pathology can be assessed. This seems to be particularly necessary to separate patients at high risk for permanent deficits or repeat events due to vascular pathology early after onset of symptoms, when the decision between ischemia and infarction is difficult.

Magnetic resonance imaging (MRI) is an excellent tool for the diagnosis of brain-stem and cerebellar infarction, and numerous reports have demonstrated its superiority over computed tomography.8-13 Although recent studies reported the diagnosis of basilar or vertebral artery occlusion on MRI in the absence of flow void phenomena or presence of high-signal intensity areas on T1-weighted images along the course of the artery,14,15 these MRI abnormalities are not of reliable diagnostic value.

Noninvasive Doppler ultrasound proved to be highly diagnostic for the detection and classification of extracranial and intracranial large artery disease,16 but topographical identification of the vertebrobasilar arterial tree proved to be difficult because of its large and complex anatomic variability.17 Thus, the combined use of this hemodynamic method with magnetic resonance angiography (MRA) providing angiogram-like images of the intracranial and extracranial arterial flow could potentially replace invasive diagnostic methods.18-23 To evaluate this hypothesis, we compared MRA findings and Doppler ultrasound with selective angiography, which is considered the “gold standard,” in patients with vertebrobasilar ischemia.

Subjects and Methods

Forty-one patients (mean age, 59.2 years [range, 28 to 81 years]; 10 women, 31 men) with unequivocal clinical
evidence of acute cerebellar and/or brain-stem ischemia were included in the study. All patients underwent neurological examination, MRI, extracranial and intracranial Doppler ultrasound, angiography, and MRA. The three examinations were all performed within 10 days after admission.

For comparison in this study, vascular pathology was determined by blinded review of the MRA projection angiograms and consensus among three readers. By means of a standardized scoring scheme, MRA findings were categorized in three groups: (1) normal; (2) stenosis (partial signal reduction or circumscribed signal loss); and (3) occlusion (loss of flow signal).

Angiographies were similarly interpreted by two radiologists, both blinded to the results of MRA and Doppler ultrasound. In accordance with the MRA evaluation, vessels were categorized as normal, stenosed, or occluded.

Doppler ultrasound pathologies as determined by two examiners before the angiographic studies were defined as normal in the case of complete vessel insolation of the distal vertebral arteries and of the basilar artery up to a depth of 110 to 120 mm. Vessel stenoses were diagnosed in the case of local increase of flow velocities. In high-grade obstructions of the distal vertebral or basilar arteries, reduced flow velocities were found in proximal vessel segments. Vessel occlusion was characterized by a damped flow signal in these segments, indicating a high-resistance pattern with undetectable local intracranial flow signal.

**Magnetic Resonance Imaging**

Magnetic resonance imaging was performed with a 1.5-T superconductive unit using a circular polarizing head coil (Magneton 63 SP, Siemens Medical Systems, Erlangen, Germany). T1-, T2-, and proton density–weighted spin-echo images were obtained at a minimum in the transverse plane to evaluate infarction. The diagnostic criterion used for infarction was an increased signal intensity in T2-weighted images corresponding to typical vascular territories.

**Magnetic Resonance Angiography**

Magnetic resonance angiography was accomplished using a first-order, flow-compensated gradient-echo technique (fast imaging with steady-state precession [FISP] three-dimensional [3-D]; repetition time, 30 milliseconds; echo time, 7 milliseconds; flip angle, 15°; field of view, 200×200 mm; matrix, 192×256; slab thickness, 64 mm; number of excitations, 1; partitions, 64). Velocity compensation was performed in the readout and slice selection direction. This type of sequence leads to a partial saturation of the brain tissue by application of multiple radio frequency impulses. Flowing blood appears bright because fully magnetized, unsaturated blood protons enter the slice. To image the extracranial distal parts of the vertebral artery and the circle of Willis, two axial slabs with a thickness of 64 mm each were fitted together with an overlap of 24 mm. Thus, two data acquisitions were obtained, which could be postprocessed using a maximum intensity projection (MIP) algorithm to create angiogram-like images.

In each patient, in addition to coronal and axial overview projections, seven coronal and three axial projection images at 15° increments were obtained of the distal vertebral arteries and of the proximal basilar artery, with restricted volume size eliminating unwanted vessel overlap and achieving better discrimination of vessel stenosis or occlusion (“targeted MIP”).

Magnetic resonance angiography was added to the routine MRA examination. Additional scanning time for MRA was 13 minutes, and total examination time did not exceed 35 minutes. Data postprocessing was performed on a separate console, requiring an additional 15 minutes.

In the case of suspected vessel occlusion in the MRA projections, the FISP 3-D single slices and the spin-echo slices were viewed very carefully to detect discrete flow signals. To ensure the diagnosis in two patients, an additional gradient-echo sequence (FLASH 2-D; repetition time, 32 milliseconds; echo time, 10 milliseconds; flip angle, 30°; field of view, 200×200 mm; matrix, 224×256; transverse orientation; 10% slice overlap; slice thickness, 4 mm; number of slices, 53; parallel presaturation of venous blood flow), which is more sensitive to low-flow velocities, was performed in the region of the suspected occluded vessel.

In five patients with basilar artery occlusion or stenosis, additional MRA sequences with presaturation studies were performed to prove retrograde blood flow in the distal basilar artery via the posterior communicating artery.

In four cases of nonconclusive findings of the distal vertebral artery, the proximal parts of the vertebral artery were examined with a Helmholtz neck coil with the aforementioned FISP 3-D sequence and three to four transverse slabs from the aortic arch to the V3 segment of the vertebral artery. Reconstruction was performed in the coronal plane beginning at the right lateral view and proceeding in 15° increments to the opposite lateral view.

**Doppler Ultrasound**

Noninvasive Doppler ultrasound examination of the extracranial arteries was performed using continuous-wave Doppler ultrasound (Debimetre Ultrasonique Delalande, 4 and 8 MHz) and color-coded duplex studies with a 7.5-MHz sector transducer system (Acuson 128). A microprocessor-controlled directional pulsed-wave Doppler device was used (TC2-64B EME, Überlingen) for transcranial examinations of the arterial system. Details of the methods and examination procedures are presented elsewhere.16

**Selective Intra-arterial Angiography**

Selective, intra-arterial catheter angiograms were performed via a femoral or brachial approach using a 4F catheter system in all patients. A 256×256 matrix and either the 13-cm or 23-cm diameter of the image intensifier (DVI 2, Philips, Eindhoven, the Netherlands) were used. Injections of 5 to 8 mL of nonionic contrast medium were performed by either mechanical injector or hand-held probe. Routinely, anterior and lateral views were obtained separately for neck and brain. Only patients with high-quality angiograms with depiction of small vessel segments were included into the study. In two patients, only one vertebral artery was injected. In one patient (Fig 1B) a selective angiography of the innominate artery via a brachial route was performed.
Results

Magnetic Resonance Imaging

Thirty-five of 41 patients had cerebellar and/or brain-stem infarctions with signal hyperintensities in T2-weighted MRI sequences. In 6 patients short-lasting brain-stem and cerebellar symptoms indicated transient ischemia without demonstrable tissue damage.

Magnetic Resonance Angiography, Doppler Ultrasound, and Digital Subtraction Angiography Findings

Vertebral artery pathologies (V3-4 segment). Selective angiography revealed 7 distal vertebral artery stenoses, 11 distal vertebral artery occlusions (Fig 1), and 1 patient with an aneurysm of the distal part of the vertebral artery.

Magnetic resonance angiography detected all distal vertebral artery stenoses (n=7) and occlusions (n=11; Fig 1), as well as the aneurysm of the vertebral artery (n=1). In 2 patients, additional FLASH 2-D sequences confirmed a high-grade stenosis with an extremely weak signal, indicating poststenotic low blood flow velocity. In 1 patient with normal MRA findings of the intracranial part of the vertebrobasilar system, a proximal vertebral artery dissection was missed.

Doppler ultrasound missed 2 distal vertebral artery stenoses and failed to differentiate a tandem stenosis of the vertebral and basilar artery. The diagnosis of distal vertebral artery occlusion was established in 9 of 11 patients.

Basilar artery pathologies. Angiography showed 3 midbasilar, 3 proximal, and 1 distal basilar artery stenoses (Fig 2), as well as 4 basilar artery occlusions (Fig 3). In 4 patients with BA occlusions and 1 patient with distal basilar artery stenosis, a retrograde filling of the distal basilar artery via the posterior communicating artery was demonstrated (Fig 4).

Magnetic resonance angiography findings correlated completely with angiographic results but showed an additional proximal basilar artery stenosis that could not be confirmed by digital subtraction angiography and Doppler ultrasound. In 4 patients with midbasilar artery occlusion and 1 patient with distal basilar artery stenosis, a suspected retrograde blood flow of the distal basilar artery could be confirmed by the additional application of saturation studies (Fig 4).

Doppler ultrasound diagnosed 3 basilar artery occlusions (n=4) and 3 basilar artery stenoses (n=7). In 1 patient with angiographically confirmed vertebral artery and basilar artery stenosis, Doppler ultrasound estab-
lished the diagnosis of vessel obstruction but could not discriminate these 2 stenoses. One patient with midbasilar occlusion was misdiagnosed as vertebral artery stenosis, and another with a basilar artery stenosis was interpreted as vertebral artery occlusion. In 2 patients, a basilar artery stenosis was not detected.

Vertebral artery pathologies (V1-3 segment). In 4 patients, digital subtraction angiography demonstrated extracranial vertebral artery dissections in the V3 segments: 1 of these 4 had collateral filling of the distal vertebral artery via the deep cervical ascending arteries, 2 showed proximal dissection of the vertebral artery resulting in distal vertebral artery occlusion, and 1 patient demonstrated a typical “string sign” of the left vertebral artery with normal distal vessel segments. In another patient, severe proximal vertebral artery stenosis was found.

Magnetic resonance angiography examination of the extracranial vertebral arteries was not performed routinely in this study. In 3 patients with clinically suspected dissection, additional MRA of the extracranial parts of the vertebral artery in a Helmholz neck coil with the FISP sequence confirmed the diagnosis corresponding to angiographic and Doppler ultrasound findings. Accordingly, a severe proximal vertebral artery stenosis was detected in the Helmholz neck coil in a patient who had had a normal MRA in the head coil.

Three of the 4 patients with proximal vertebral artery dissection and 1 patient with severe proximal stenosis were correctly diagnosed.

A summary of the vertebrobasilar artery system findings is depicted in the Table.

The diagnostic sensitivity of MRA and Doppler ultrasound for the detection of vertebrobasilar artery pathologies was 97% and 76.4%, respectively, and the specificity was 98.9% for both.

Discussion

This prospective study of 41 patients with vertebrobasilar ischemic disease shows a high sensitivity and specificity of MRA versus conventional arteriography for the detection of obstructions of the vertebrobasilar system. This is true for both the detection of abnormalities such as stenoses and occlusions and the topographical location of the underlying process.

**FIG 3.** Patient with acute bilateral pontine brain-stem infarction. Magnetic resonance angiography (A) and digital subtraction angiography (B) show midbasilar artery occlusion (arrows).

**FIG 4.** Patient with acute bilateral pontine brain-stem infarction (same patient as Fig 3). A, digital subtraction angiography demonstrates retrograde filling of the distal basilar artery via posterior communicating artery (arrow). B and C, Magnetic resonance angiography saturation (SAT) study. Presaturation of both carotid siphons (B) leads to loss of flow signal in the superior cerebellar arteries and the posterior cerebral arteries (arrow) as indirect sign of retrograde blood flow in the distal basilar artery (C). Compare Fig 4C with Fig 3A. Axial reconstruction of the circle of Willis (not shown) displayed both posterior communicating arteries. ACI indicates internal carotid artery and BILAT, bilateral.
Vertebrobasilar Artery Pathology as Diagnosed by Magnetic Resonance Angiography and Doppler Ultrasound Compared with Digital Subtraction Angiography in 41 Patients

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*MRA, magnetic resonance angiography; DUS, Doppler ultrasound; DSA, digital subtraction angiography; VA, vertebral artery; BA, basilar artery.

*Concerning DUS evaluation, vertebrobasilar obstructions were ranked true-positive, regardless of the proper localization of disease in the distal VA or BA.

We found that the sensitivity of MRA for correctly diagnosing distal vertebral and basilar artery pathologies was 97%, whereas the specificity was 98.9%. The sensitivity of Doppler ultrasound in comparison to angiography was 76.4%, with a specificity of 98.9%. In only one patient with a proximal vertebral artery dissection and normal filling of the distal vertebral artery via cervical collateral arteries was the diagnosis missed by the combined results of MRA and Doppler ultrasound.

Considering the excellent sensitivity of MRA in our study, it is necessary to point out that MIPs of entire-volume MRA data result in the visualization loss of small vessels and details. Therefore, we suggest targeting MIPs to selected vessels or certain vascular territories, which results in a gain of image quality and higher spatial resolution.

Another factor that accounts for the good correlation of MRA with digital subtraction angiography and Doppler ultrasound is the straight course of vessels in the vertebrobasilar system. Thus, signal loss caused by turbulence blood flow in curved arterial segments is a minor problem.

Potential difficulties of MRA of the vertebrobasilar arteries lie in the proper evaluation of absent or low blood flow signal. The flow signal in MRA is highly dependent on the flow velocity. For example, a weak flow signal of the distal vertebral artery can be the result either of proximal stenosis or occlusion or of hypoplasia. In these patients, sequences more sensitive to slow blood flow such as FLASH 2-D and MRA of the extracranial vertebral arteries can deliver decisive information. This requires additional examination time, which is not always tolerated by the patients. Therefore, in this study MRA was mainly restricted to the intracranial portion of the vertebral artery, while only few patients (n=4) with clinically suspected vertebral artery dissection or normal MRA of the intracranial vertebrobasilar arteries were examined by extracranial MRA. Since stenoses at the origin of the vertebral artery are a frequent finding in patients with vertebrobasilar ischemia, MRA of the extracranial arteries is mandatory in patients with Doppler ultrasound evidence of extracranial vertebral artery disease and in the case of nonconclusive findings on MRA of the intracranial portion of the vertebrobasilar arterial supply. In these problematic cases, Doppler ultrasound examination is an important tool for screening the extracranial vertebral artery and helps to concentrate the MRA examination on specific parts of the vertebrobasilar arteries.

Doppler ultrasound in this study showed a sensitivity and specificity of 76.4% and 98.9%, respectively, for the identification of the underlying pathology, with smaller validity (sensitivity, 72.7%; specificity, 97.8%) when the topography of the lesion was considered. This supports recent results published by Mull et al17 that the diagnostic validity of transcranial Doppler ultrasound is markedly improved when combined with either angiographic method.

The evaluation of the hemodynamic relevance of stenoses of the vertebrobasilar arteries remains a major problem for both Doppler ultrasound and MRA; although Doppler ultrasound may improve classification of degrees of obstructions, correlation is difficult because of the extension of artificial signal loss in high-grade stenoses as a result of widespread turbulence.24 Similar to MRA classifications of internal carotid artery stenoses compared with conventional angiography and Doppler ultrasound.25

The lack of information on the hemodynamic situation of static MRA can be overcome in part with the application of the saturation technique, which allows an analysis of flow directions and collateral flow conditions at least at the level of larger arteries.15 This method was successfully applied in our study in five patients with basilar artery stenosis or occlusion and retrograde blood flow in the distal part of the basilar artery (Fig 3).

We find that MRA and Doppler ultrasound form complementary tools for a noninvasive diagnosis of intracranial vertebrobasilar artery system. While MRA delivers angiogram-like images of the vessels and their pathology, Doppler ultrasound adds the hemodynamic information, which cannot be obtained by MRA alone. With the combination of both methods, reliable diagnosis of obstructive vertebrobasilar artery disease can be made.

Considering our data, the diagnostic workup of large, distal, vertebrobasilar artery disease can readily be made by MRA and Doppler ultrasound if they deliver coincident results. Selective angiography is required in patients with diverging results of MRA and Doppler ultrasound or with disease of vertebral artery origin.

References


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